Electrostatic self-assembly of microsphere lens arrays

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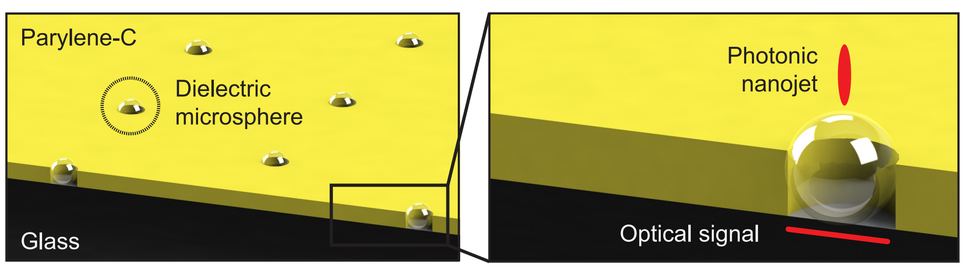
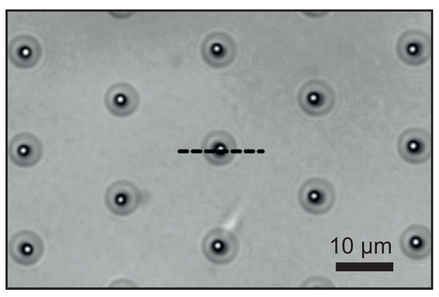
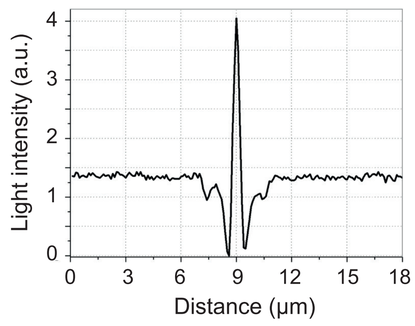
We propose a novel versatile method for the rapid and low-cost fabrication of microsphere arrays to be used as lenses of desired geometry and optical properties. Our method is based on the electrostatic self-assembly of dielectric microspheres in Parylene-C/glass well templates, with the array geometry patterned in a Parylene-C layer. We demonstrate here a process that uses 3 µm-size melamine spheres. We use optical tweezers to assess the electrostatic nature of the microsphere binding mechanism by manipulating the patterned spheres. We demonstrate that our method ensures extremely fast and reliable array formation and offers moreover the possibility to reversibly assemble and disassemble the lens array by tuning the pH of the microsphere patterning and washing solutions. Furthermore, we successfully employ our microlens arrays to significantly enhance on-chip detection of fluorescenty labeled bio-molecules.

Microsphere lens array overview

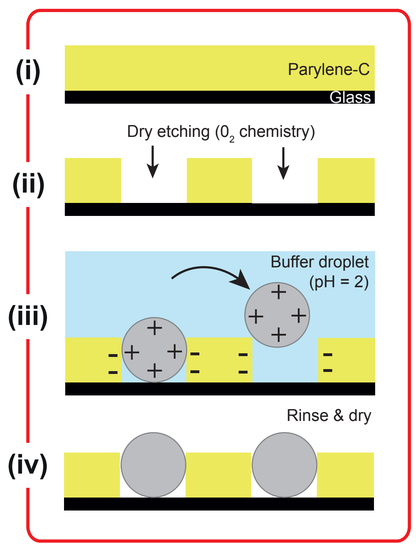




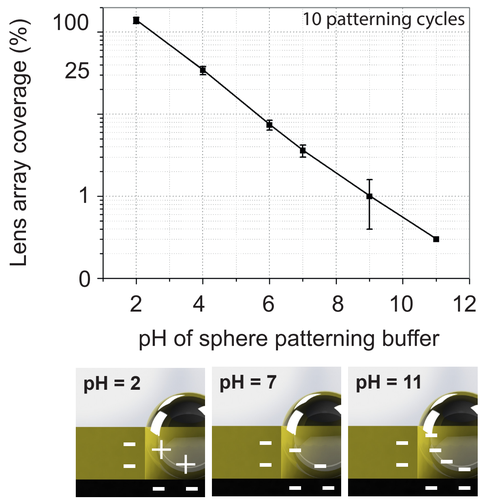


- Dielectric microspheres are trapped inside Parylene-C/glass microwells with high loading efficiency (> 99%) by simply transporting a droplet containing suspended microspheres over the microwell surface.
- The microwell size allows controlling the number of patterned particles, down to the single lens per well.
- An optical signal going through a single microlens is focused in a highly localized spot of enhanced intensity, also known as 'photonic nanojet'.
- The self-assembled microlens arrays enable to confine light at desired locations and provide 3-fold or higher signal enhancements.

Electrostatic lens self-assembly



Microfabrication process flow. (i) Parylene-C deposition on glass substrate. (ii) Anisotropic etching of Parylene-C layer. (iii) Microsphere patterning cycles (3-10 cycles). 1 cycle = 1 passage of a bead suspension droplet over the array (iv) Lens array rinsing and drying.

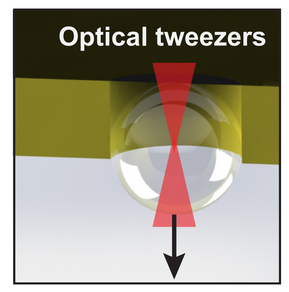


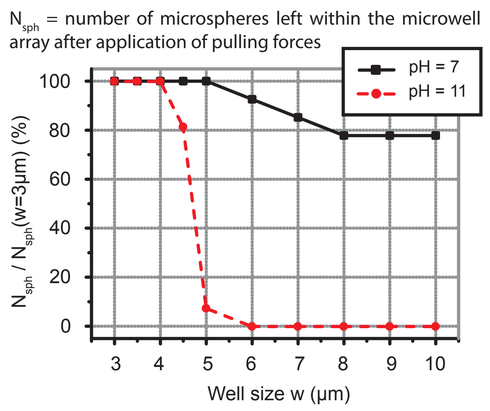
Electrostatic nature of the self-assembly process. The particle loading efficiency strongly depends on the pH of the buffer used for the patterning. For 3 µm carboxyl-functionalized melamine microspheres, higher efficiencies are obtained for lower pH values, as confirmed by considering the isoelectric point of the particles, the Parylene-C layer and the glass substrate.

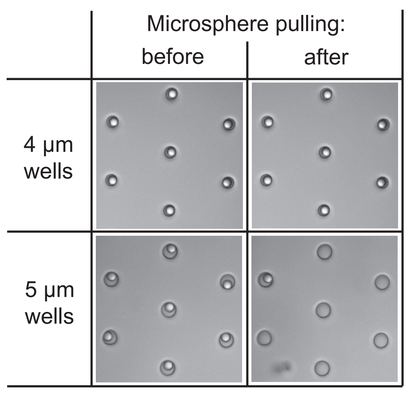
References: [1] Yang, H.; Gijs, M.A.M. *Anal Chem*, 2013, 85, 2064-2071.

Lens immobilization analysis

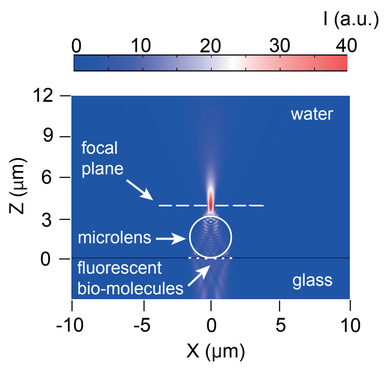
An accurate analysis of the lens immobilization efficiency is carried on by employing optical tweezers to exert a constant pulling force on single patterned microspheres, immobilized within microwells of different sizes. This analysis illustrates the crucial role of the interaction between spheres and microwell walls for the stable lens immobilization as well as the possibility of reversibly assemble and disassemble the lens array via electrostatic forces.



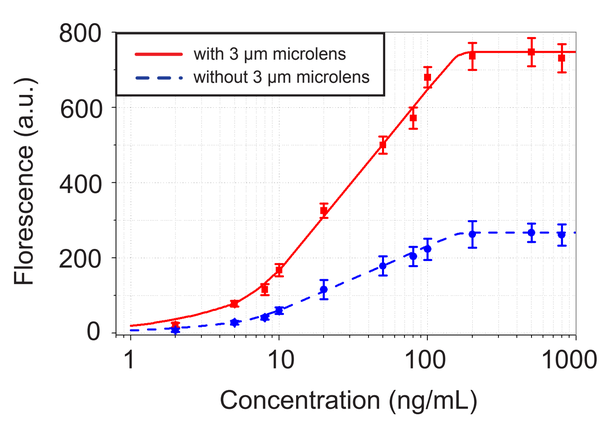




Enhanced bio-molecule detection



Finite Element Method (FEM) simulations. 3 µm dielectric microparticle, positioned on a flat light source (e.g. formed by fluorescently labeled bio-molecules), to be used as a microlens for optical signal enhancement.



Experimental results. On-chip detection of fluorescently labeled bio-molecules (mouse IgGs) at different concentrations, in presence and in absence of 3 µm microlenses. The fluorescent signal enhancement due to each microlens results in a more efficient molecule detection.[1]

Conclusion & Outlook

We developed and systematically characterized a novel method for the fabrication of microlens arrays by electrostatic self-assembly of dielectric microspheres in Parylene C/glass well templates. We studied, both theoretically and experimentally, the optical properties of our lens arrays and we successfully employed them to enhance on-chip biomolecule detection. We believe that this work provides a substantial impact towards the fabrication of microlens arrays of tailored optical properties in a rapid, low-cost, versatile and efficient way, for many applications in the growing field of lab-on-a-chip systems, such as the development of integrated immunoassays and point of care diagnostic tools which use read-out of an optical/fluorescent signal.

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